An Intelligent Under Frequency Load Shedding Scheme for Islanded Distribution Network

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***Abstract*-- In islanding mode, system frequency is severely disturbed due to imbalance between generation and load demand resulting in overloading or loss of generation cases. In order to cope with these events, under-frequency load shedding scheme (UFLS) is applied to stabilize the frequency. This paper presents an intelligent under frequency load shedding scheme implemented on mini-hydro operating in islanded mode. The proposed UFLS scheme consists of a fuzzy logic load shedding controller (FLLSC) with load shedding controller module (LSCM). The FLLSC by measuring frequency and rate of change of frequency estimates the amount of load to be shed. The LSCM sheds the load estimated by FLLSC. This scheme is tested for event based and response based cases. The results have shown that proposed load shedding scheme successfully estimates the amount of load to be shed and stabilizes the frequency for these cases.**

***Index Terms*— Event Based case, Fuzzy Logic control, Mini Hydro, Response Based case**

I. Introduction

THE increased penetration of distributed Generation (DG) in power system network may lead to its commercialization all around the world. A DG may be any small type of electrical power generation installed in a distribution system having capacity less than 10MW [1]. DG can comprise of any renewable energy source like wind turbine, photovoltaic array, micro turbine, fuel cells, conventional diesel and natural gas reciprocating engines. A DG of Mini hydro power plants have been also connected to the grid, mainly in rural area. These plants are cost-effective since it doesn't required dam and water storage. Furthermore, it is environmental friendly. Despite of advantages that a DG based Mini hydro has, its implementation in a network can cause various problems to the existing network mainly on safety and security of the system.

One of the problems is when a distribution network that connected with DG electrically islanded from main grid. The network is called islanded system. When islanding occurs in a distribution network, voltage and frequency are severely disturbed due to imbalance between generation and load demand [2]. This large frequency variation may lead to power collapse, if not recovered quickly and properly. To avoid this, under frequency load shedding scheme is performed to shed some load in order to keep system running, though at reduced capacity. Load shedding through frequency relay is the most common type of UFLS technique for frequency control under abnormal conditions. In this technique, the under frequency relay will operate when system frequency falls below a certain threshold, and shed some amount of electrical power in step-wise manner [3-6]. This UFLS technique cannot ensure system security and reliability. Since, the amount of load to be shed is not accurately estimated. Thus, to improve its performance, adaptive and intelligent load shedding schemes have been proposed in [6-9].

An adaptive UFLS scheme employs power swing equation to estimate the amount of load to be shed. The literature on adaptive UFLS scheme has reported that the most UFLS schemes are based on voltage variation to identify and shed the sensitive load buses [10], a combination of frequency, df/dt and voltage changes [11] and initial slope of df/dt for setting the under-frequency relays [12]. The frequency response of an islanded system is more severely disturbed when subjected to transient than the interconnected grid system. Hence, these systems require more robust techniques to stabilize the frequency. The under frequency load shedding scheme proposed by various authors for islanded system are based on frequency and df/dt information, customers willingness to pay and load histories [13] and best time to shed the loads[14].

This paper proposes a new intelligent UFLS scheme for load shedding. It consists of fuzzy logic load shedding controller (FLLSC) with load shedding controller module (LSCM). The FLLSC first determines the type of load disturbance whether event based or response based and estimates the power imbalance. FLLSC send the signal to LSCM which shed the required load to stabilize the frequency. The load is shed according to load priority. The proposed scheme is implemented on distribution network that consists of two small units of hydro generation operating in islanding

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mode. The overview of proposed UFLS scheme is explained as below:

II. Overview of Proposed Load Shedding Scheme

This paper proposed a fuzzy based under frequency load shedding strategy to shed optimum loads in an islanding mode to stabilize the system frequency. Proposed UFLS strategy is based on frequency and df/dt information. Fuzzy logic load shedding controller (FLLSC) uses these values as input and intelligently estimates the power imbalance during load disturbances. FLLSC after estimating the power imbalance sends this value to load shed controller module (LSCM) for shedding loads according to load priority. Combination of event based and response based method are used for applying load shedding scheme in the network. Standard frequency pick value to begin load shedding scheme is 49.5Hz [15]. FLLSC calculates the value of fall in frequency and disturbance magnitude. If frequency value is less than 49.5Hz, load shedding strategy will operate to shed the load to stabilize frequency. Fig.1. illustrates the overview of load shedding scheme for an islanded distribution network connected with MHPP-type DG.

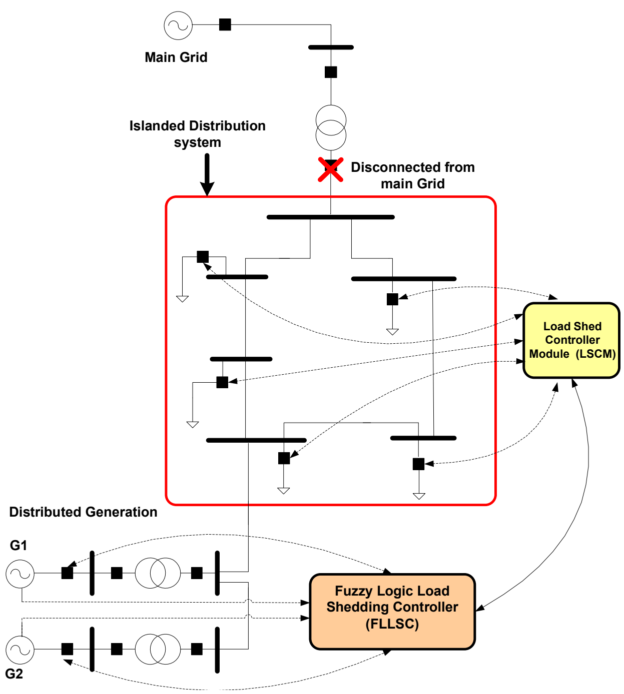

Fig.1. Proposed load shedding scheme layout

III. Methodology for Proposed UFLS Scheme

Proposed UFLS scheme introduces fuzzy logic approach for islanded system and is based on system frequency, df/dt and load prioritization. The scheme consists of two main modules:

(a) Fuzzy Logic Load Shedding Controller (FLLSC)

(b) Load Shed Controller Module (LSCM).

FLLSC continuously monitors mini hydro power plants frequency (f1 and f2) and is responsible for determining system state at every instant of time. FLLSC checks whether any of MHPP is disconnected from network. If this happen, network frequency will follow to the frequency of mini hydro unit that is still in operation. If both mini hydro units are still in operation, average frequency (f) of both is taken.

When a load disturbance (event based or response based) occurs in the system, FLLSC monitors frequency whether it drop to certain value (49.5 Hz). If this happens, FLLSC determines its state and estimates amount of load to be shed. If estimated amount ΔP is greater than ΔP_{max}, FLLSC sends estimated amount of ΔP to LSCM for shedding respective loads to stabilize the frequency. However, if estimated amount is less than ΔP_{max}, FLLSC do not sends signal to LSCM, the generator remains operating without requiring any load to be shed. The loads are classified into three categories; vital, semi-vital and non-vital. Non-vital loads have the lowest priority and will be shed first followed by semi-vital and vital loads. The load priority table is shown in Table IV given in Appendix. FLLSC sends estimated value to LSCM via communication link. Real time measurement and Remote Circuit Breaker (RCB) are facilitated at each of the load feeder. The system state variable measurement (i.e. active power, frequency and voltage) are monitored by FLLSC whereas breakers status are monitored by LSCM. In FLLSC, there are two strategies; (1) event based and (2) response based scheme. Event based case may occur when one of mini hydro unit is tripped during islanded mode. This may happen due to islanding operation when power generated by generating unit is insufficient to supply total load. Response based case occur due to sudden increment of load in an islanded system. In this case, number of load to be shed depends on the disturbance magnitude. FLLSC decides right strategies based on frequency, df/dt and breaker status at the mini hydro units.

IV. Modeling of Fuzzy Logic Load Shedding Controller (FLLSC)

The modeling of fuzzy logic load shedding controller (FLLSC) is designed in PSCAD software. Since, PSCAD software does not provide fuzzy logic tool, Fuzzy logic load shedding controller (FLLSC) is designed in PSCAD by writing C-program. The C-program is interfaced with system within PSCAD. This method has an advantage that system presents all simulation aspects within a single integrated environment. Hence, simulation time is fast. Fuzzy logic load shedding controller (FLLSC) has two inputs (frequency and rate of change of frequency) and one output (Lshed, ΔP). Fuzzy logic load shedding controller receives frequency and rate of change of frequency as input signal, and estimates amount of load to be shed. The linguistic variables membership functions of input frequency are Low, Vlow (very low), Extlow (extremely low), Vextlow (very extremely low), and input membership functions of rate of change of frequency (df/dt) are HN (High Negative), LN (low negative), LP (low positive), MP (more positive). The linguistic variables of output Lshed are Vsshed (very small shed), Sshed (small shed), Bshed (big shed), Vbshed (very big shed).

Fuzzy logic load shedding controller comprises of fuzzification, rule base, inference mechanism and defuzzification steps as shown in Fig.2.

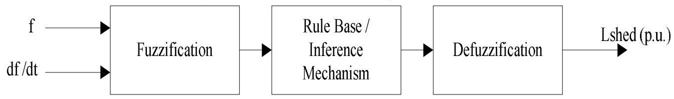

Fig.2. Block diagram of proposed FLLSC

In fuzzification, real input values are converted into fuzzy set values, which assign degree to which these inputs belong to each of the appropriate fuzzy sets. Fuzzification is carried out through equation of slope. A snapshot for determining membership degree of member ship function (Low) of frequency input is shown in Fig.3 and explained by equations (1)-(4).

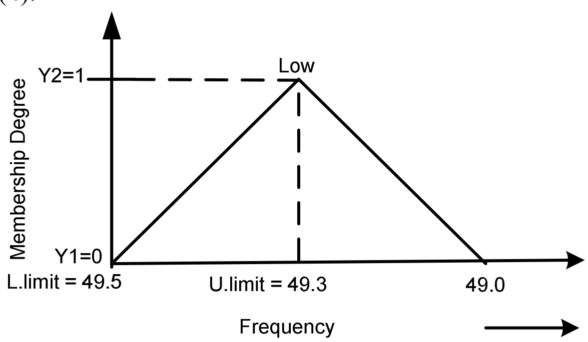

Fig.3. Snapshot of frequency error fuzzification

$$Equation\ of\ Slope = \frac{y2 - y1}{x2 - x1} = \frac{y - y1}{x - x1} \quad (1)$$

$$Slope = m = \frac{y2 - y1}{x2 - x1} \quad (2)$$

$$\frac{y2 - y1}{u.limit - l.limit} = \frac{m.degree - y1}{frequency - l.limit} \quad (3)$$

$$m.degree = slope\ x\,(frequency - l.limit) + y1 \quad (4)$$

All the membership functions of fuzzy based governor consist of triangular membership functions as they provide smooth control and are shown in Fig.4-6.

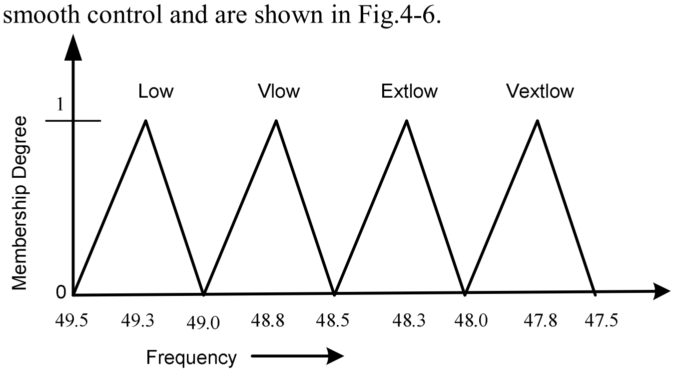

Fig.4. Frequency membership functions

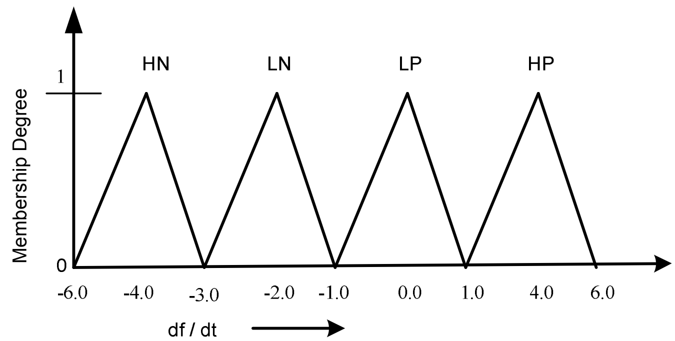

Fig.5. Rate of change of frequency (df/dt) membership functions

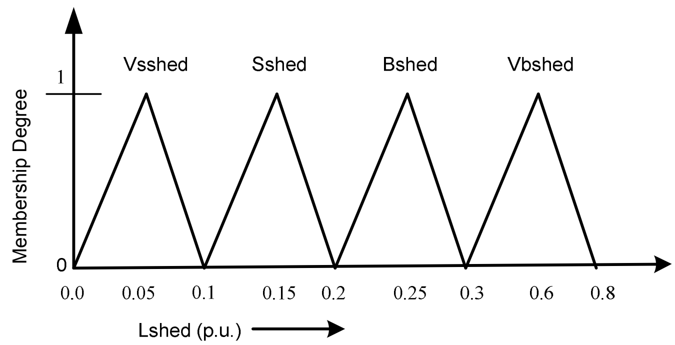

Fig.6. Load shed (Lshed) membership functions

Fuzzy based governor input and output membership functions are formed in C-program by using one dimensional array concept. The triangular membership functions are divided into two slope equations for fuzzification. The one dimensional array in C-program for Fig. 3 is given as:

float low[3]={49.5,49.3,49.0}

For vertical axis another one dimensional array is employed representing the corresponding values of membership function along vertical axis:

float vert[3]={0,1,0};

where vert represents the vertical axis and values 0, 1 and 0 are corresponding values of -6, -3 and -1 along vertical axis as shown in Fig. 3.The triangular membership functions are divided into two slope equations for fuzzification.

Fuzzy rule base is applied in IF-THEN rule form to assign the input and output control such as:

IF frequency is low and df/dt is LN THEN Lshed is Vsshed
IF frequency is Vextlow and df/dt is HN THEN Lshed is Vbshed.

The other rules of fuzzy logic load shedding controller are summarized in Table.1.

TABLE I

RULE TABLE FOR FLLSC

		Frequency			
		Low	**Vlow**	**Extlow**	**Vextlow**
(df / dt)	**HN**	Sshed	Bshed	Bshed	Vbshed
	LN	Sshed	Sshed	Bshed	Vbshed
	LP	Vsshed	Vsshed	Ssshed	Sshed
	HP	Vsshed	Vsshed	Vsshed	Vsshed

Inference mechanism evaluates active signals for taking control actions from the fuzzy rules. Finally, defuzzification is carried out through weighted average to convert the fuzzy linguistic variable into real values. The advantage of this method is that it is computationally fast, easier and provides accurate results.

V. TEST SYSTEM FOR PROPOSED UFLS SCHEME

The test system for analyzing the proposed UFLS scheme consists of a two mini-hydro power plants modeled in PSCAD/EMTDC software. Each mini hydro unit has a capacity of 2 MVA and is working in parallel operation. The distribution system consists of 27 buses, 20 lumped loads, 16 remote circuit breakers (RCB) and is islanded from the main grid. It is assumed that distribution system is facilitated with fast communication links for monitoring the breakers status and data. The mini hydro power plant mainly consists of governor, turbine and generator for conversion of mechanical energy into electrical energy. The basic function of governor is to control the speed of the generator so that its frequency remains constant. This paper employs PID controller as governor. The hydro turbine is a mechanical device which converts the potential energy of the water head into mechanical energy. The hydraulic turbine considered in this paper is of non-elastic water column without surge tank. Test system with two mini hydro power plants and distribution network is shown in Fig.7.

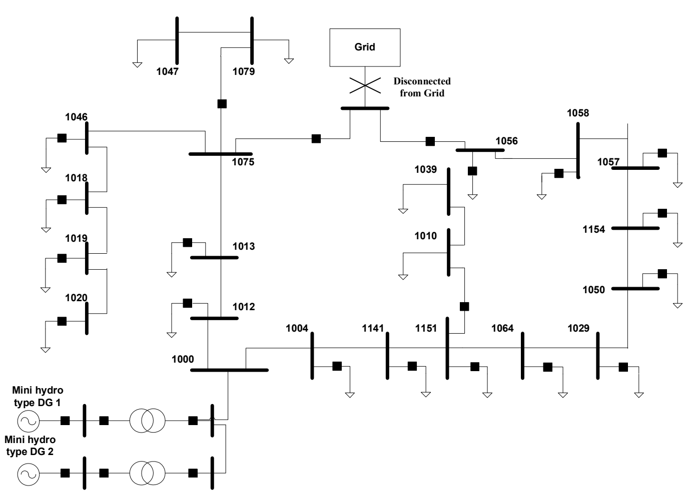

Fig.7. Test system model for load shedding scheme

VI. CASE STUDIES

This research includes the case studies of under frequency load shedding (UFLS) scheme. Under frequency load shedding scheme involves event based and response based case studies. All case studies of load shedding scheme are tested on islanded distribution network connected with mini hydro units.

A. Event Based Load Shedding Case

To simulate event based load shedding case, one of the generators is tripped from the islanded distribution system. Since, the loads in islanded system are supplied by two mini-hydro power plants; loss of one generator will give a great impact to islanded system. As a result, all load is shifted to the remaining operating generator. Since, load is beyond the maximum capacity of generator unit and need to be shed in order to able generator unit operating continuously. If load shedding scheme is not applied, frequency will drop below 47.5 Hz and will never be recovered, resulting in power blackouts.

The event based load shedding is applied at t=30 s by tripping one generator. The FLLSC checks first frequency limit of 49.5 Hz. After checking this, FLLSC check about type of load disturbance applied on islanded distribution system. FLLSC by monitoring RCB status of mini hydro units determines that system encountered event based load disturbance. FLLSC estimates the amount of load to be shed and sends signal to LSCM, which immediately trip significant number of load feeders to stabilize the frequency. The frequency response of mini hydro power plant for this case is shown in Fig.8.

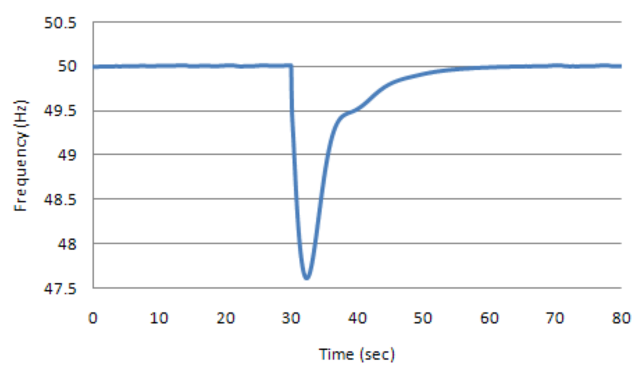

Fig.8. Frequency response during event based case

From the Fig.8, it can be observed that mini hydro has frequency undershoot of 47.62 Hz and frequency stables within 30 s. The load shedding values, power saving and breakers tripped during event based load shedding case are shown in Table II.

TABLE II
LOAD SHEDDING VALUES DURING EVENT BASED CASE

Case	Undershoot	Power Supplied	Amount of Load Shed	Total no. of Breakers Operated
Event Based Case	47.62 Hz	1.47MW (73.5%)	1.03 MW	10

It can be observed that FLLSC estimates correct amount to shed in this case and LSCM successfully shed the required load to stabilize the system frequency.

B. Response Based Load Shedding Case

To simulate response based load shedding case; the mini hydro power plants are tested with load increments of 0.6 MW and 1MW. By adapting proposed UFLS scheme, FLLSC again checks for frequency limit of 49.5 Hz. FLLSC by monitoring RCB status of mini hydro power plants determines that system encountered response based load disturbance. FLLSC by measuring frequency and rate of change of frequency (df/dt) estimates the amount of load to be shed for 0.6 MW and 1MW load increment cases. If estimated amount ΔP is greater than ΔP_{max}, FLLSC sends estimated amount of ΔP to LSCM for shedding respective loads to stabilize the frequency. However, if estimated amount is less than ΔP_{max}, FLLSC do not sends signal to LSCM, the generator remains operating without requiring any load to be shed. The frequency response and power graph for this case are shown in Fig.9.

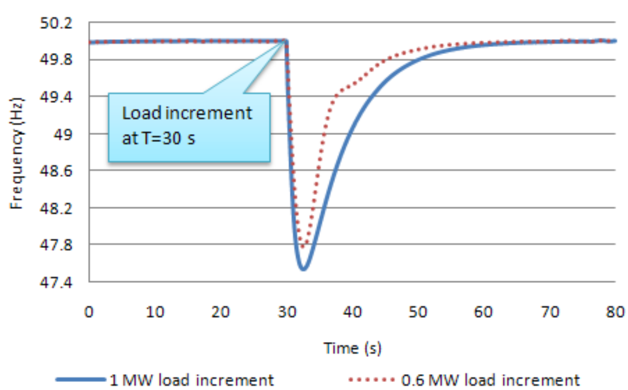

Fig.9. Frequency response during response based case

From the Fig.9, it can be observed that for 0.6 MW load increment case, generator frequency has undershoot of 48.43 Hz and frequency stabilizes in 30 s. Whereas for 1MW load increment case, generator frequency has undershoot of 47.52 Hz and frequency stabilizes in 30 s. The load shedding values and breakers tripped during this case are shown in Table III.

TABLE III
LOAD SHEDDING VALUES DURING RESPONSE BASED CASE

Response Based Case	Undershoot	Power Supplied	Amount of Load Shed	Total no. of Breakers Operated
At 0.6 MW Case	48.43 Hz	0.3852MW from 0.6MW	0.2148 MW	4
At 1MW Case	47.52 Hz	0.57MW from 1MW	0.43 MW	6

From the Table III, it can be observed that with an overloading of 0.6 MW and 1MW at system, the FLLSC intelligently estimates the power imbalance and LSCM shed the load to stabilize system frequency.

VII. CONCLUSION

The paper proposed new intelligent under frequency load shedding scheme for islanded distribution network. From the simulation results, it can be observed that proposed UFLS scheme estimates the amount of load to be shed according to disturbance magnitude. The fuzzy logic load shedding controller (FLLSC) intelligently distinguishes between event based and response based cases and estimates power imbalance to shed the load. FLLSC send this value to load shed controller module (LSCM) for shedding the estimated load in one step. Proposed method can prevent the frequency drop by shedding optimal load in order to maintain the system stability. In one glance, this algorithm can improve and enhance the system frequency response.

VIII. APPENDIX

TABLE IV
LOAD PRIORITY TABLE FOR LOAD SHEDDING SCHEME

S. No	Bus Number	P(MW)	Q(MVAR)	Load Category
1	1013	0.0456	0.0282	Non-vital
2	1141	0.0531	0.033	Non-vital
3	1012	0.0531	0.033	Non-vital
4	1050	0.063	0.0384	Non-vital
5	1047-1079	0.11721	0.07281	Non-vital
6	1057	0.126	0.0768	Non-vital
7	1058	0.132	0.0819	Non-vital
8	1010-1039	0.15009	0.0933	Non-vital
9	1018	0.11619	0.072	Semi-vital
10	1004	0.14151	0.0876	Semi-vital
11	1020	0.1845	0.11439	Semi-vital
12	1046	0.1701	0.1053	Semi-vital
13	1154	0.1401	0.0849	Semi-vital
14	1064	0.093201	0.057801	Semi-vital
15	1029	0.2313	0.1431	Semi-vital
16	1019	0.10671	0.06609	Vital
17	1151	0.107199	0.06639	Vital
18	1056	0.35259	0.2187	Vital

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